An Astronomical Skeleton Clock

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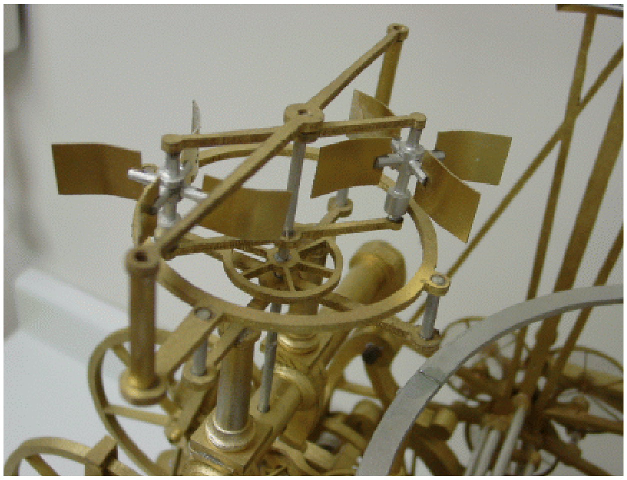
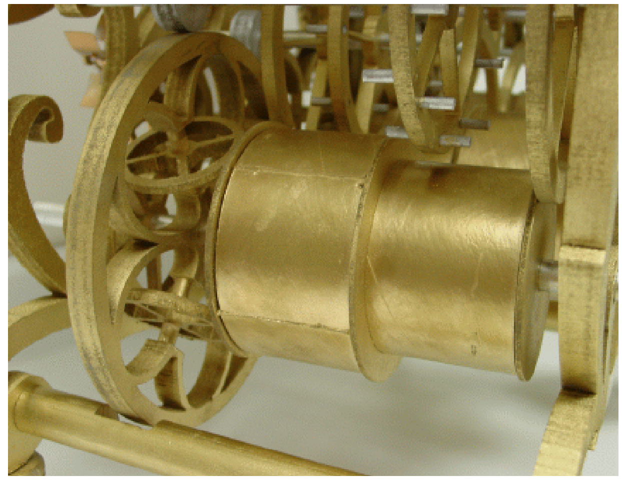
Overview:
This is a wooden mockup of a three train, quarter striking skeleton clock with additional train for astronomical functions. Planned features: All trains will be equipped with epicyclical maintaining power. Eight day duration. Dual escapement and pendulum layouts are loosely based on John Harrison's grasshopper design as applied in his H1 sea clock and have a four second period. Drive to the escapement is supplied through independent dual remontoire based upon Jean Wagner's swinging frame design.* Remontoire period are each 30 seconds. Celestial train tripped once per minute. All *twenty one complications* are driven from this train and all are demonstrate able together or separately in forward or reverse. Orrery capable of demonstration in two different magnitudes of speed. Movement, net 25"w x 29"h x 16"d, case 36"w x 77"h x 24"d. Estimated gross weight 600-700 lb. net without weights 300 lb. Movement to be built by Buchanan of Chelmsford, Australia. * For more information about remontoire see my paper at: http://www.my-time-machines.net/remontoire.htm

Philosophy behind the design:
I wanted to create for lack of a better term, my 'dream clock'. It had to incorporate four main principals: Scale, complexity, movement and, of course, beauty. The combination is employed to maximize *visual impact.* This is reflected in the design of the remontoire and strike flies. The use of 90 degree triple-set bevel wheels for the equation, remontoire and maintaining power systems in place of flat sun and planet differentials - let alone the conventional systems more commonly seen. The dual remontoire and counter-rotating escapement systems. The strike train's operation is altered from convention to make maximum use of their special flies. All moons being operational for Jupiter and Saturn in the orrery. Even the rate at which the compound pendulums oscillate was carefully chosen to give a hypnotic effect - thus a longer period of four rather than the standard two seconds.

It took two years to think through the design; what I wanted the clock to do, the dial layout, escapement, remontoire design and other specifics like the fly fan designs. I borrowed liberally from the master clock makers of the past. The remontoire from Jean Wagner, escapement from John Harrison, strike flies from Fasoldt, orrery from Janvier, tellurium from P. Hahn, equation work from Tompion, frame from Condliff.

My biggest fear was that, while each component may be beautiful in it's own right, the amalgamation may look like...well just an amalgamation. A careful six month collaboration between myself and the fabricator, Buchanan of Chelmsford, who is clockmaker with skills equal to any of the masters from horological history, helped to bring about the mockup you see.

What I wanted to represent in the astronomical parts of the clock was a depiction of the world around us at various scales. Also the ability to demonstrate how the things we see with our own eyes look like from near and farther into space. When the celestial train is demonstrated one will see the interaction of the sky as it would be from my home town with the stars and sun moving across the sky in the planisphere. The Sun and Moon rising and setting in their separate dials as well as the length of the day and night relative to each other. The ability to see when all these things happen contemporaneously as well as in the past and future. Then moving a bit into space to see the Earth - Moon system around the sun through the tellurium and how this system effects the way we see the stars and sun in the planisphere and Sun - Moon rising, setting dials. Finally, a further magnitude of distance and we see the entire solar system (at least as it was known to Janvier in the late 18th century). This looks back into the tellurium, planisphere and finally the Sun-Moon dials. At this scale we see how much smaller our place in His creation really is!

The mockup contains only the main wheels and rough outlines of the actual clock. Even so, it is quite an impressive work for wood and paper and represents only a fraction of the final wheel and parts count. It is estimated that the finished product will contain over 200 wheels and 5000 parts.

Construction time - three years. You will be able to see the clock as it is built beginning January 2007 on my web site: www.my-time-machines.net.

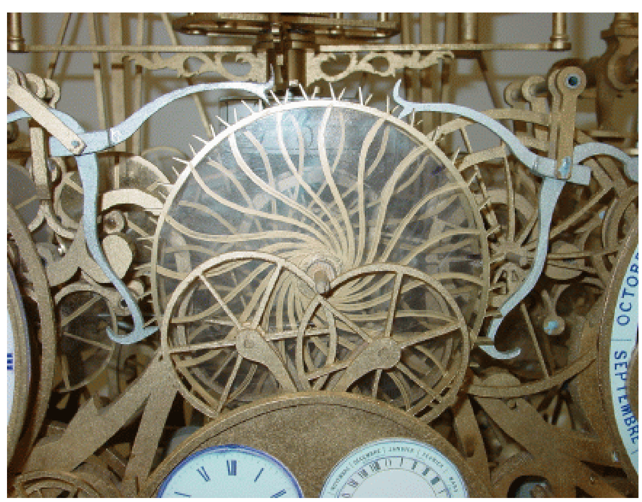
Highlights:
<u>Jeweling</u>. *All pivots* are jeweled throughout the clock (including orrery). The going train including remontoire and all antifriction wheels supporting the escapement wheels as well as the pendulums have jeweled chatons. Exception being the main wheels (barrels) and first wheel up each train. These are in chaton roller bearings with faux jeweling to hide the bearing. Escapement pallets and other sliding surfaces jeweled.

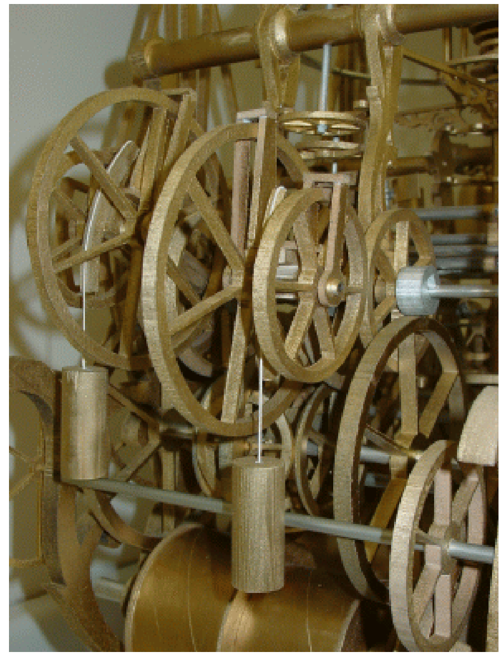
<u>Materials</u>: All plates are of yellow brass and lacquered. Wheels between the plates of deep pink bronze, wheels outside the plates a lighter shade of bronze. Chatons from silver bronze. Arbors and all ferrous metal from stainless steel (with exception of screws, pinions and pivots). Arbor pivots fitted to stainless arbors with appropriate hardened tool steel. Pinions fitted to arbors from hardened chrome steel. All dials porcelain from Swiss maker Donze Cadrans. Dial bezels to be knurled and gold plated.

<u>Construction</u>: Overall workmanship is on the order of a fine watch. Buchanan's work is as good as seen on any modern or, for that matter, antique clock. All arbors will be tapered. All screws blued to 'electric' blue color. Other parts blued where appropriate such as hands, clicks and their springs. *All wheels* screwed with three blued screws to their respective collets - no press fitting. Number of wheel crossings will vary depending upon size and location of wheels. Six spokes being predominant, and nowhere less than four. All surfaces brought to a fine, high polish. This step alone is estimated to take six months. All cocks, bridges and other parts attached to the frame to be equipped with guide pins.

All astronomical subsystems as well as dial work will be designed to be removable from the clock without having to part the main plates. By the same token the clock is designed with every part being able to be taken down to it's individual component - no non-removable, i.e. glued, fused, soldered or welded parts.

Operation:
Two large, counter-rotating, 40 tooth escape wheels ride upon sets of anti-friction wheels. Both with independent grasshopper escapements are, in turn, each controlled by a four second period compound pendulum. The spokes on each escape wheel are specially shaped and spaced to give a kaleidoscope effect when operating. The pendulums are slaved together so as to keep the escapements in step relative to each other. The dual escape wheels are driven by separate remontoire, each of a 30 second period and operate in a stepping manner with one starting it's period half way through the other's cycle. Thus each compound, vertical fly located above the main dial works are activated every 15 seconds.

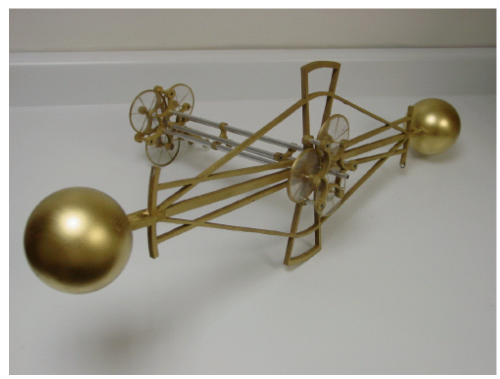




Since the period of the pendulums is four seconds, the main clock dial's second hand will move every two seconds. The remontoire are driven by a differential connected to the rest of the going train.

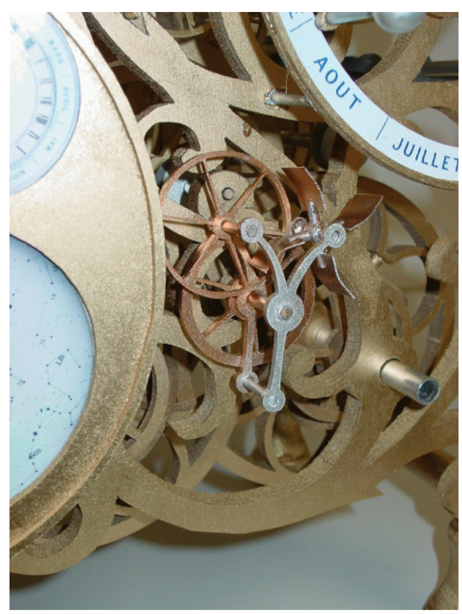
Each fly mediating the remontoire consists of two smaller flies, each with four blades that are attached to a common rotating armature. The flies are driven by an internally toothed ring gear so when the armature rotates the flies appear to do a pirouette around each other. The upper pivots of the flies and armature will have a faceted jewel to give a dazzle effect when activated.

Arbors that drive the remontoire flies (as well as the strike train flies and each escape wheel) are made from 6-sided stock, twisted and polished. This gives the effect of the power 'traveling' in the direction of the fly when activated.



The celestial train is tripped once per minute by the going train and is mediated by it's own fly. All complications (with the exception of the calendar) are driven via this train. This allows one to disconnect the celestial train from the going train without stopping the clock; enabling demonstration of the astronomical indicators at will and will be done through a hand crank.

All astronomical indicators can be demonstrated together or separately. Forward or reverse. The orrery, since it has very slow orbits for the outer planets, can be demonstrated separately at a faster speed that would otherwise be too fast for the other indicators which cycle on a daily to yearly basis.

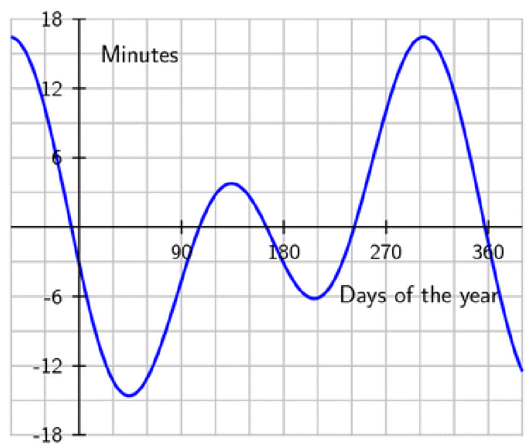


The strike train operates in a special manner to make use of both the quarter and hour strike flies every 15 minutes. There are three bells, each specially cast and tuned for this project from the Whitechapel bell factory, England. On the first three quarters the small and medium bells are struck in the normal manner for a 'bim-bam' effect, one through three times. For each of these quarters the largest bell is also struck once, afterward. On the fourth quarter the 'bim-bam' is struck four times with the largest bell striking the hour in the conventional manner. Each fly is mounted in a rotating cage made of stainless steel to make it's movement stand out from the frame. These, like the remontoire flies mounted above, also perform a pirouette, but in a totally different manner.

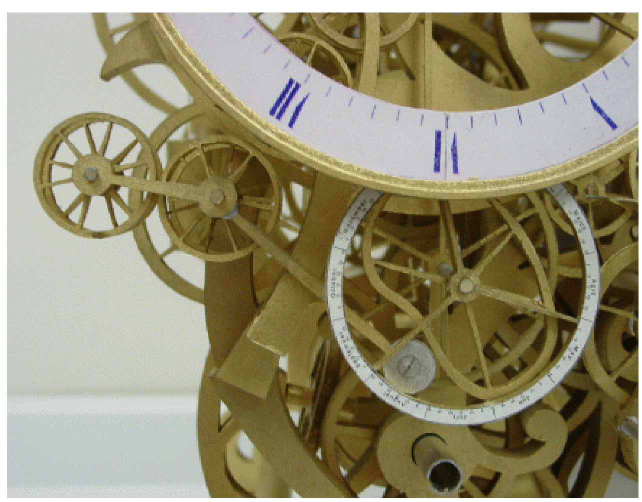
Dial description and explanation of functions:

Mean solar time - Indicates the regular local time we are all familiar with - ‘clock’ time. Seconds, minutes, hours.(Black colored hands).

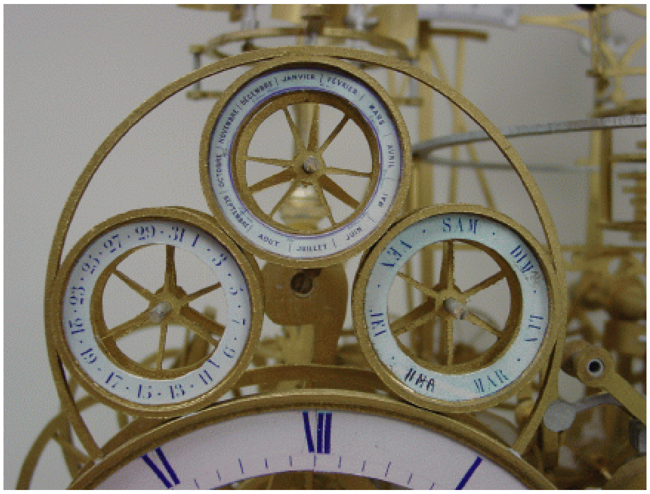
Equation of time - indicates the difference between clock time and ‘sun time’ according to the relative position of the sun in the sky as would be measured by a standard sun dial. (Gold colored hand with sun).



The earth's orbit around the sun is elliptical, not circular - and the axis of it's daily orbit is inclined at 23.45 degrees to the plane of that orbit. These factors combine, on the one hand to give us the seasons, while on the other, they present the sundial with the problem of an irregularity in the apparent movement of the sun. Unless corrected, only on four days of the year will sundial time coincide exactly with the more regular 'clock' time. The formula for this correction is the *Equation of Time.* At first the difference was calculated using intricate tables to adjust the time between regular and sundial time. Later these formulas were represented mechanically via a kidney shaped cam which rotated once per year and could then be read off a dial. An idler arm follows this cam and when attached to a hand, the difference can be read off a sector dial directly. The addition of a differential gear system (used here) allows a ‘sun dial’ minute hand to move ahead or behind the regular minute hand by the amount of the difference between the two time systems as they vary continuously throughout the year. This is from just under -14 minutes around mid February when ‘sun time’ is slow relative to ‘clock’ time; and just over +16 minutes at the beginning of November when ‘sun time’ is fast relative to ‘clock time’. There are also two minor peaks in mid-May when sun time is nearly 4 minutes fast and in late July when sun time is just over 6 minutes slow, hence the kidney shape. (See graph above.)

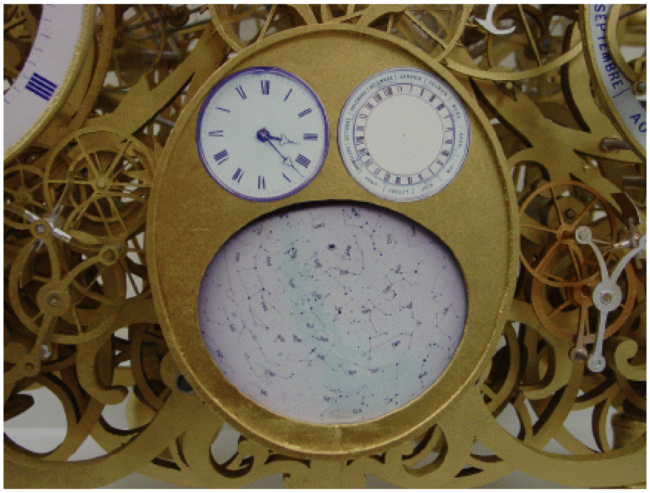


Perpetual calendar - accounts for leap years and is accurate for 400 years. This is the only complication driven by the going train.



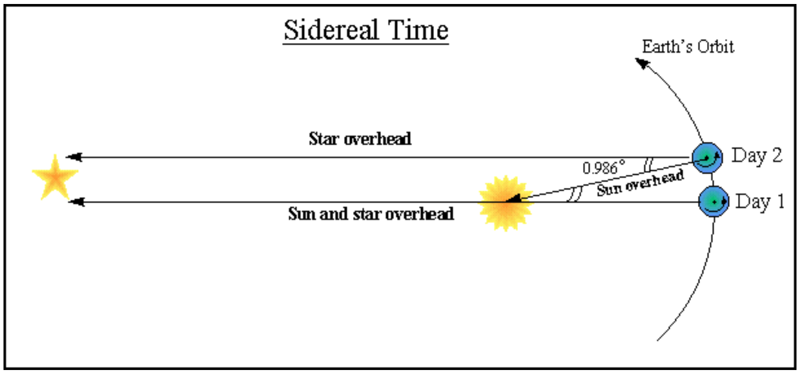
The calendar currently in worldwide use for secular purposes is based on a cycle of 400 years comprising 146,097 days, giving a year of average length 365.242375 days. The Gregorian calendar is a modification of the Julian calendar in which leap years are *omitted* in years divisible by 100 but *not* divisible by 400. By this rule, the year 1900 was *not* a leap year (1900 is divisible by 100 and *not* divisible by 400), but the year 2000 *was* a leap year (2000 is divisible by 400). The total number of days in 400 years is therefore given by 400 x 365 + 100 - 3 = 146,097. This also gives an exact number of 146,097 / 7 = 20,871 weeks per 400-year cycle.

Planisphere - Showing stars as they would appear during night (or if visible) daylight periods for the latitude of Chicago, Illinois at 41 degrees 52 minutes 11 seconds. The sun also is depicted as it would be traveling through the sky during daylight periods.



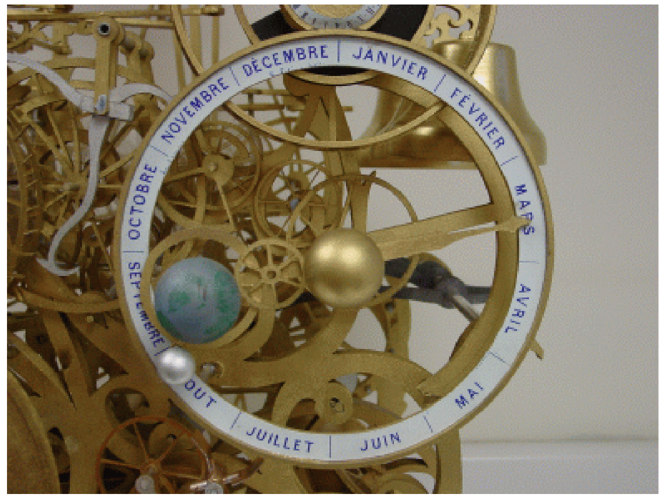
Setting rings for planisphere - (right dial, will be skeletonized). The outer ring has months and days denoted. The inner ring is marked in 24 hours allowing for accurate positioning of the planisphere's star plate.

Sidereal time - (left dial, will be skeletonized), also known as 'star time'. During the course of one day, the earth has moved a short distance along its orbit around the sun, and so must rotate a small extra angular distance before the sun reaches its highest point. The stars, however, are so far away that the earth's movement along its orbit makes a generally negligible difference to their apparent direction and so they return to their highest point in slightly less than 24 hours. A mean sidereal day is about 23h 56m 4.1s in length.



Therefore, if the mean solar time clock and sidereal time clock were synchronized at 12:00 Midnight on January 1st, the sidereal clock will tend to run faster than the regular clock by 3 minutes 55.9 seconds per day. After one year this difference will accumulate to exactly one day and both clocks will again read the same time at 12:00 midnight the following year. The dial is denoted in the standard 12 hour rather than usual 24 hour format to make comparing the difference between the sidereal and mean solar time dials easier.

Leap years do not effect this relationship as these are man-made constructs to make our numeration of whole days fit into a single year when, in fact a year is a fractional number of days.

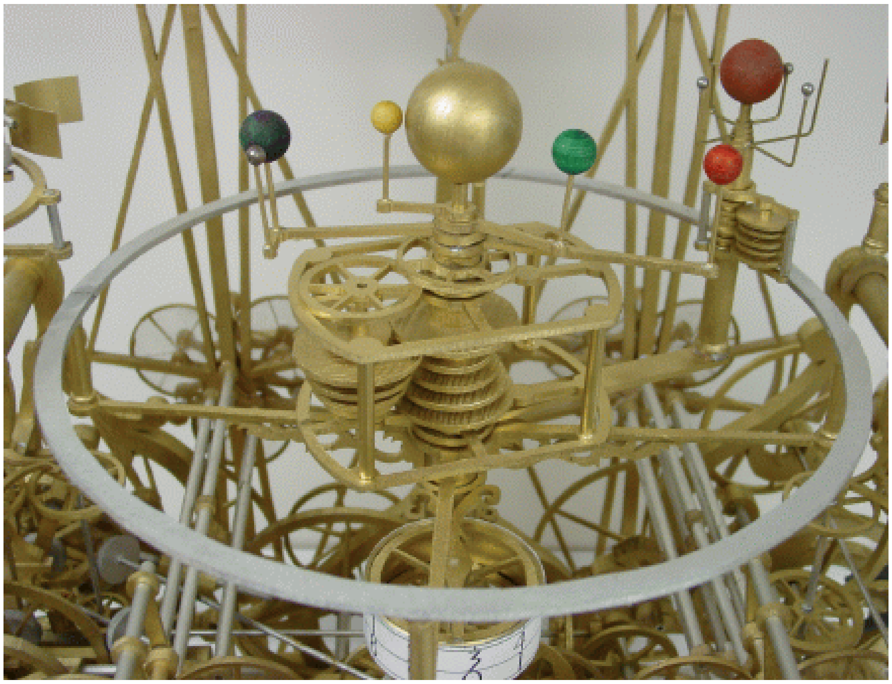


Tellurium - depicting the Earth-Moon-Sun orbital system. Pointer to annular ring indicating date and month. Semi-circular counterweight behind dial to balance system.

Sun rise and sun set indicator, (below, inner ring) - Sun globe goes around once a day. Moveable shutters (black) rise and fall with the length of the days according to the seasons. This gives the relative lengths of day vers. night. Center dial shows time of sun rise and set, (black hands). Gold sun hand shows where sun is when behind shutters. Vernier scales on shutters will show length of day and night.

Moon rise and moon set indicator, (outer ring) - Moon goes around once a day. Moveable shutters (black) rise and fall to indicate when the Moon will rise and sink below the Earth's horizon. Moon travels in front of shutters which indicate when the moon is rising during night vers. during daylight since the moon can been seen sometimes during daylight hours. Moon also rotates to give it's age and the equator is engraved with the daily age 1 through 29.5. Inner dial indicates time of sun rise, set and position. Dual nodal indicator (not shown) predicts solar and lunar eclipses; tide indicator (not shown).

Orrery, (next page). Fully functional orrery depicting all of the planets and their moons as known in the late 18th century. Sun rotates, moons orbit at correct velocities and planets orbit within their correct *elliptical orbits.* However, unlike in reality all planets do orbit within one plane. Their relative distances from the sun have been distorted to keep the orrery a reasonable and legible size (inner planets a bit further and outer planets much closer, to the Sun). Two band dials located below the orrery are used to set the orrery back to it's correct position after demonstration. These will be delineated in months and years.

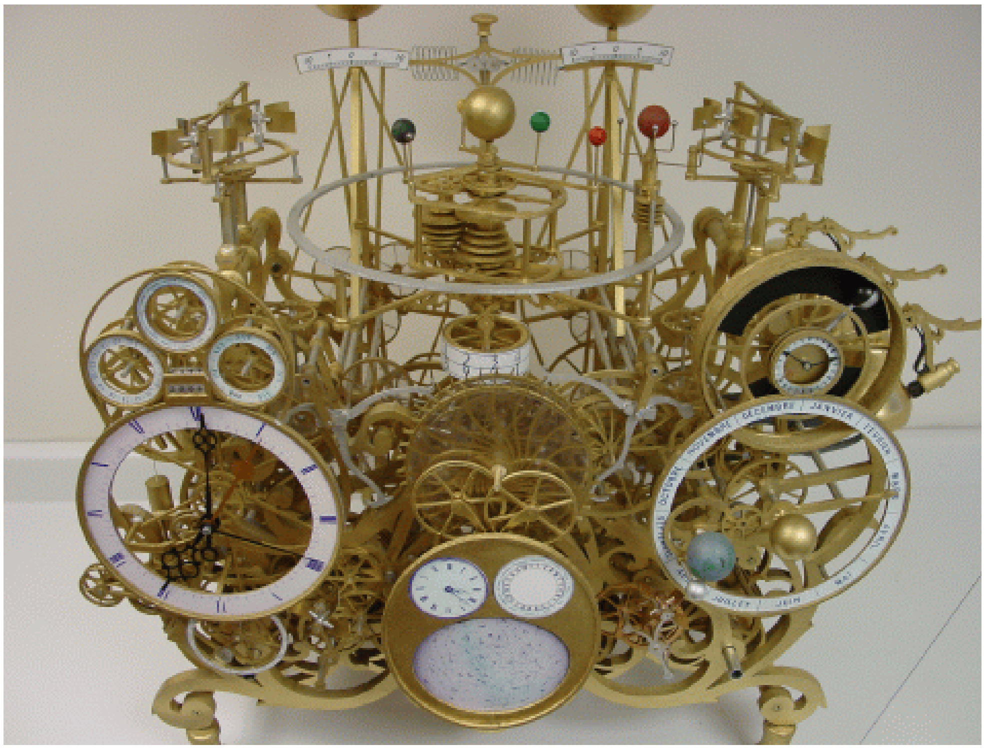


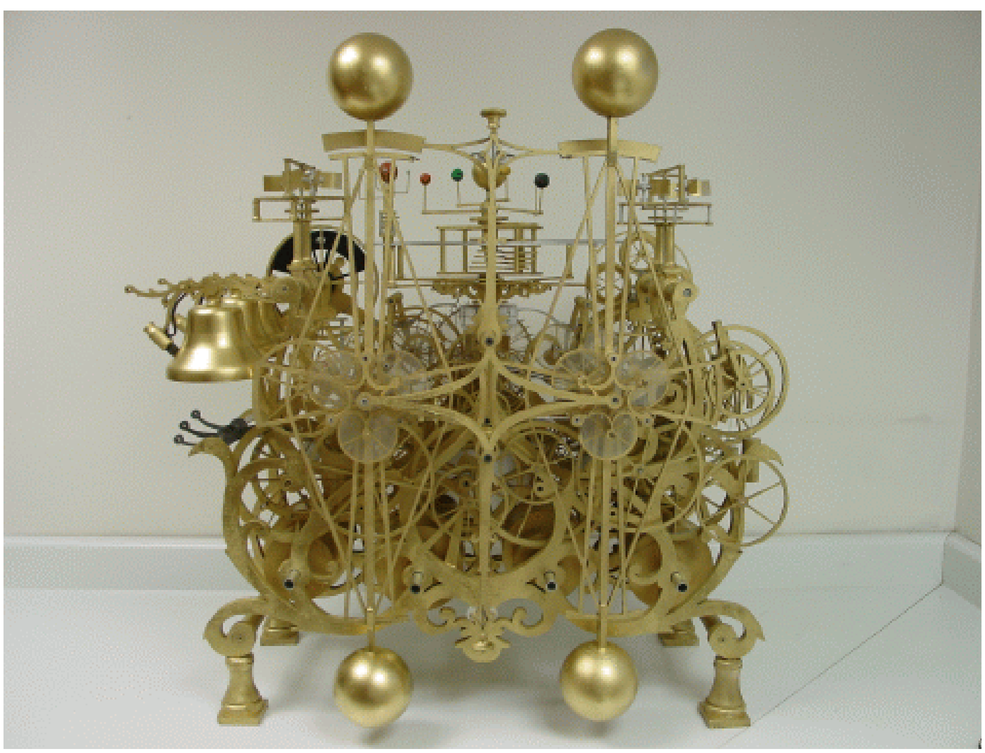
Layout from the sun outward as follows:

Planet	Satellite	Orbital period (Sun is rotational period)
Sun		27 days (approximate)*
Mercury		87.969 days
Venus		224.701 days
Earth		365.256 days
	Moon	27.322 days
Mars		686.981 days
Jupiter		4332.71 days (11.86 years)
	Callisto	16.689 days
	Europa	3.551 days
	Ganymede	7.154 days
	Io	1.769 days
Saturn **(not shown in mockup)**		29.458 years w/ 25.33 degree tilt for planets and it's moons
	Dione	2.737 days
	Iapetus	79.330 days
	Rhea	4.518 days
	Tethys	1.888 days

Titan	15.945 days

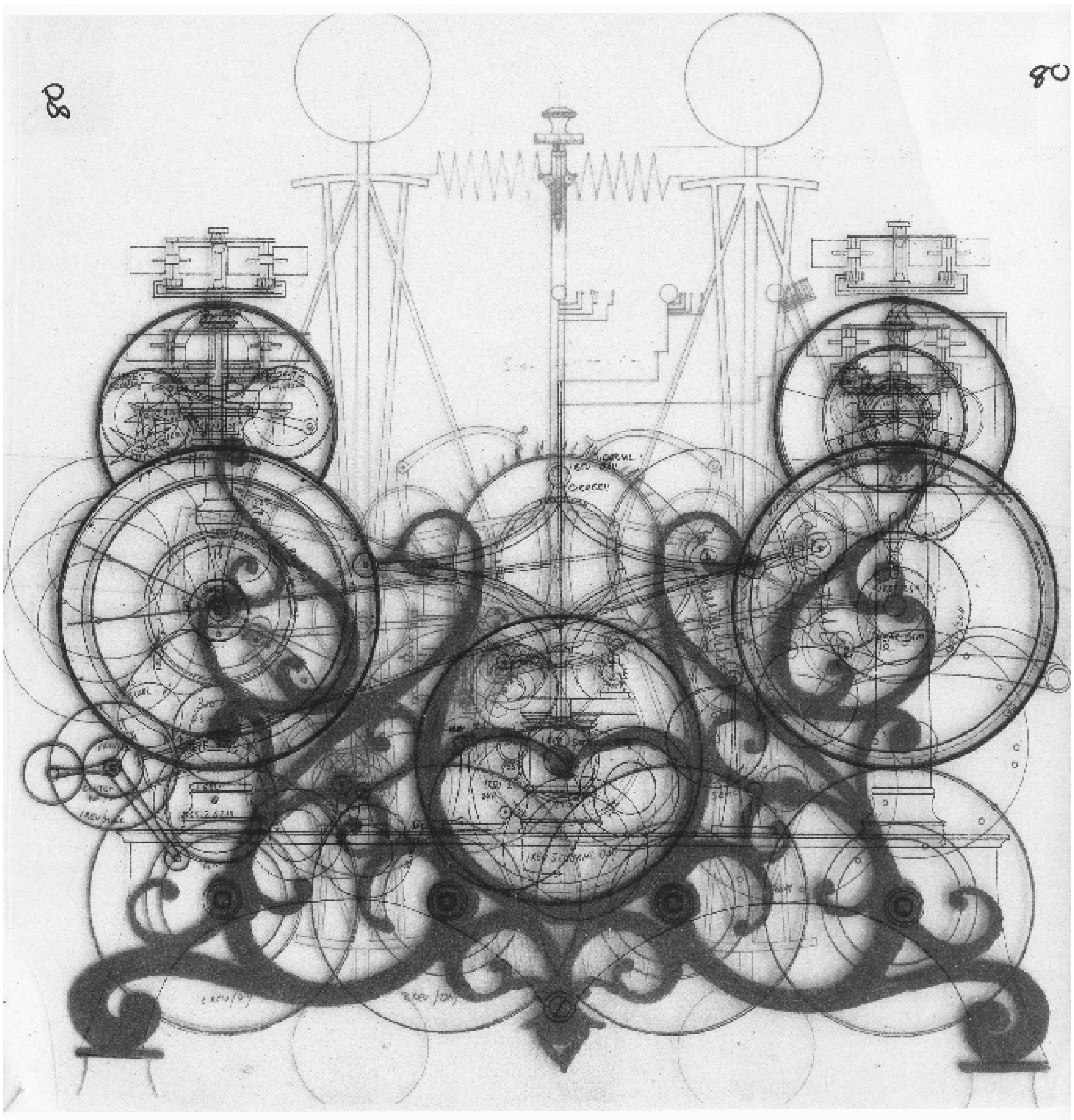
* The Sun is largely gaseous so speed varies over it’s surface from 25 days at the equator to 36 days at the poles. Deep down, below the convective zone, everything appears to rotate with a period of 27 days.



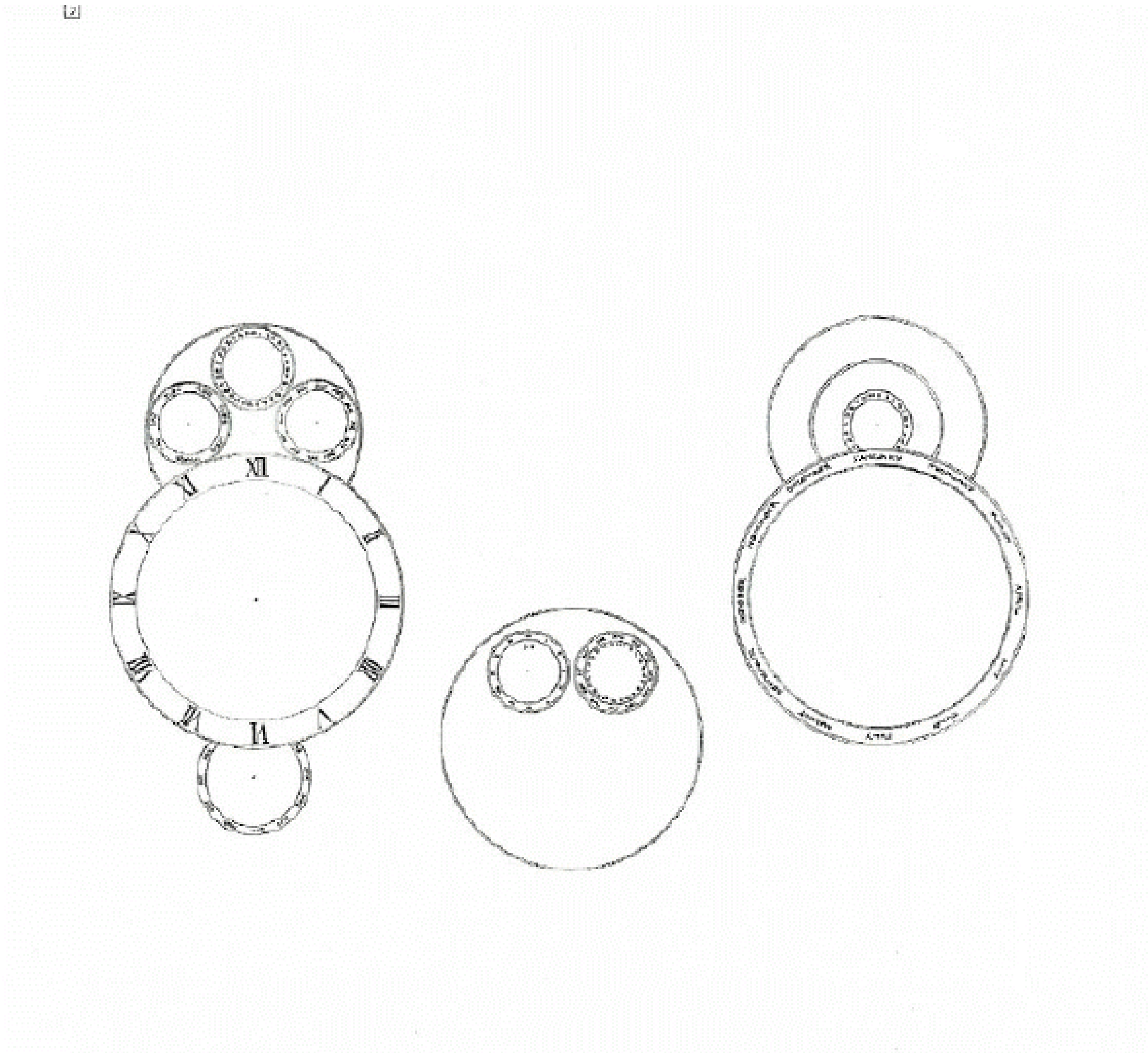


The following drawings show only a fraction of the clock works. They are meant to be instructive and not all inclusive!

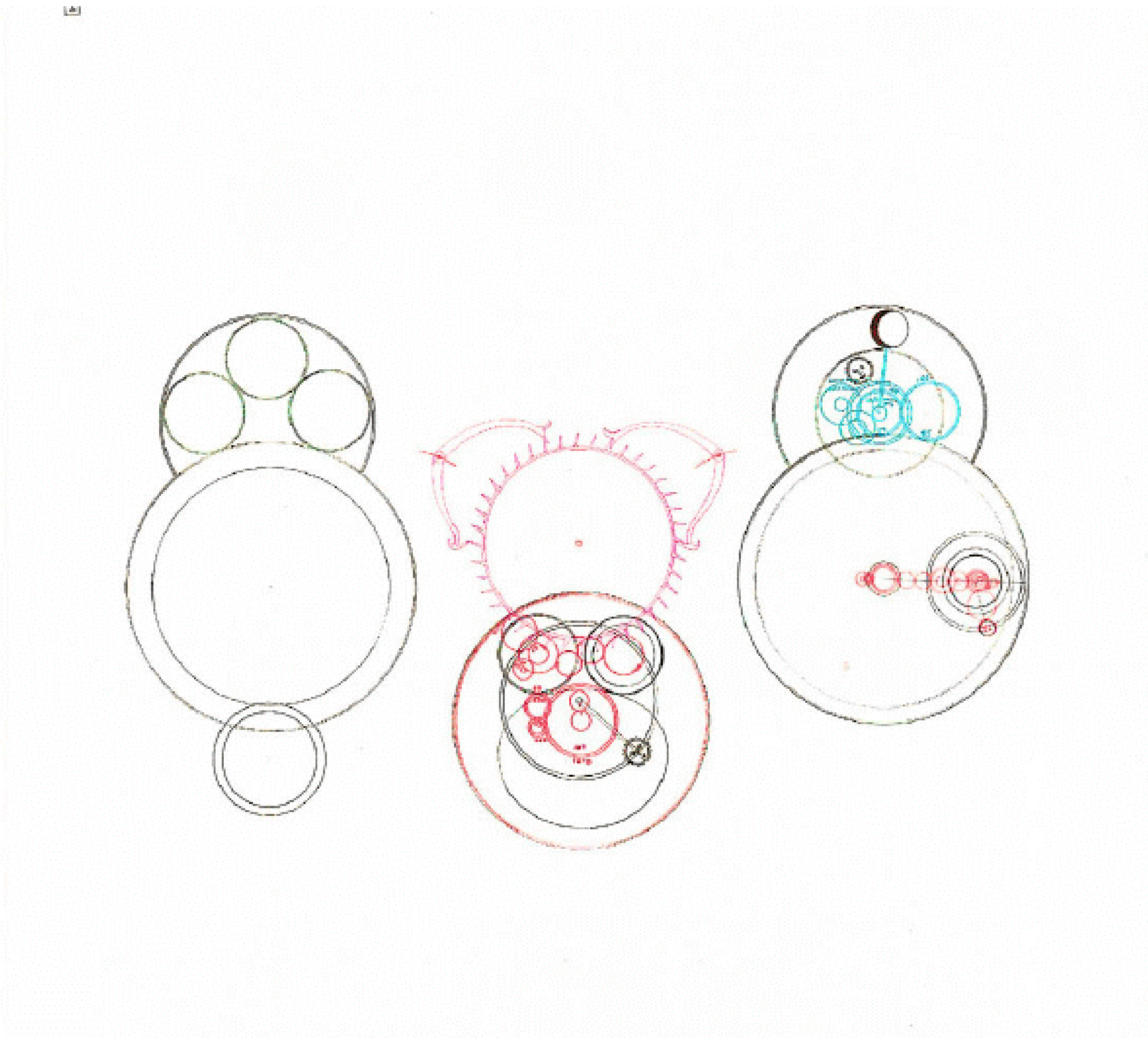
An overall view showing some of the complexity.



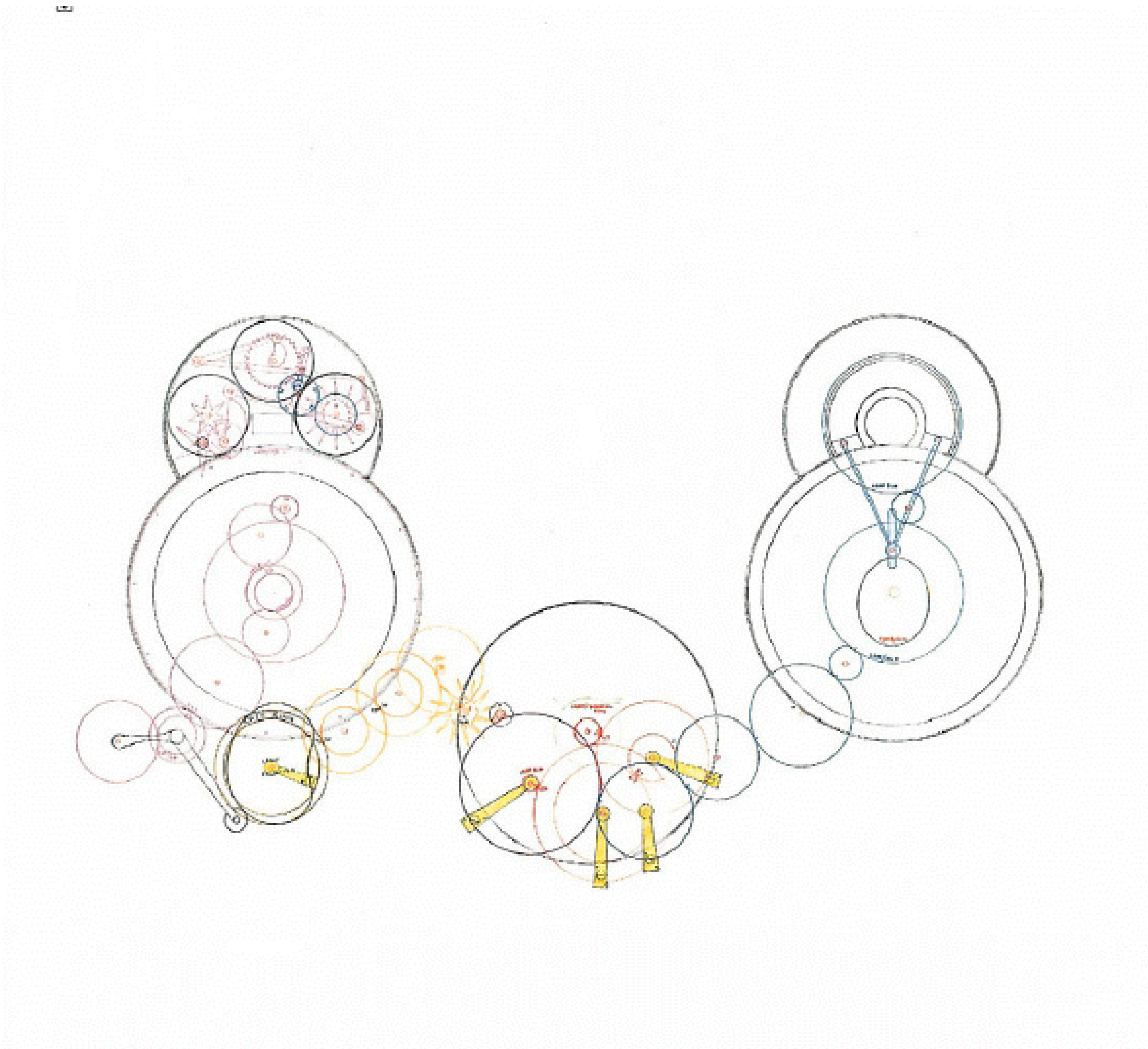
Dial work



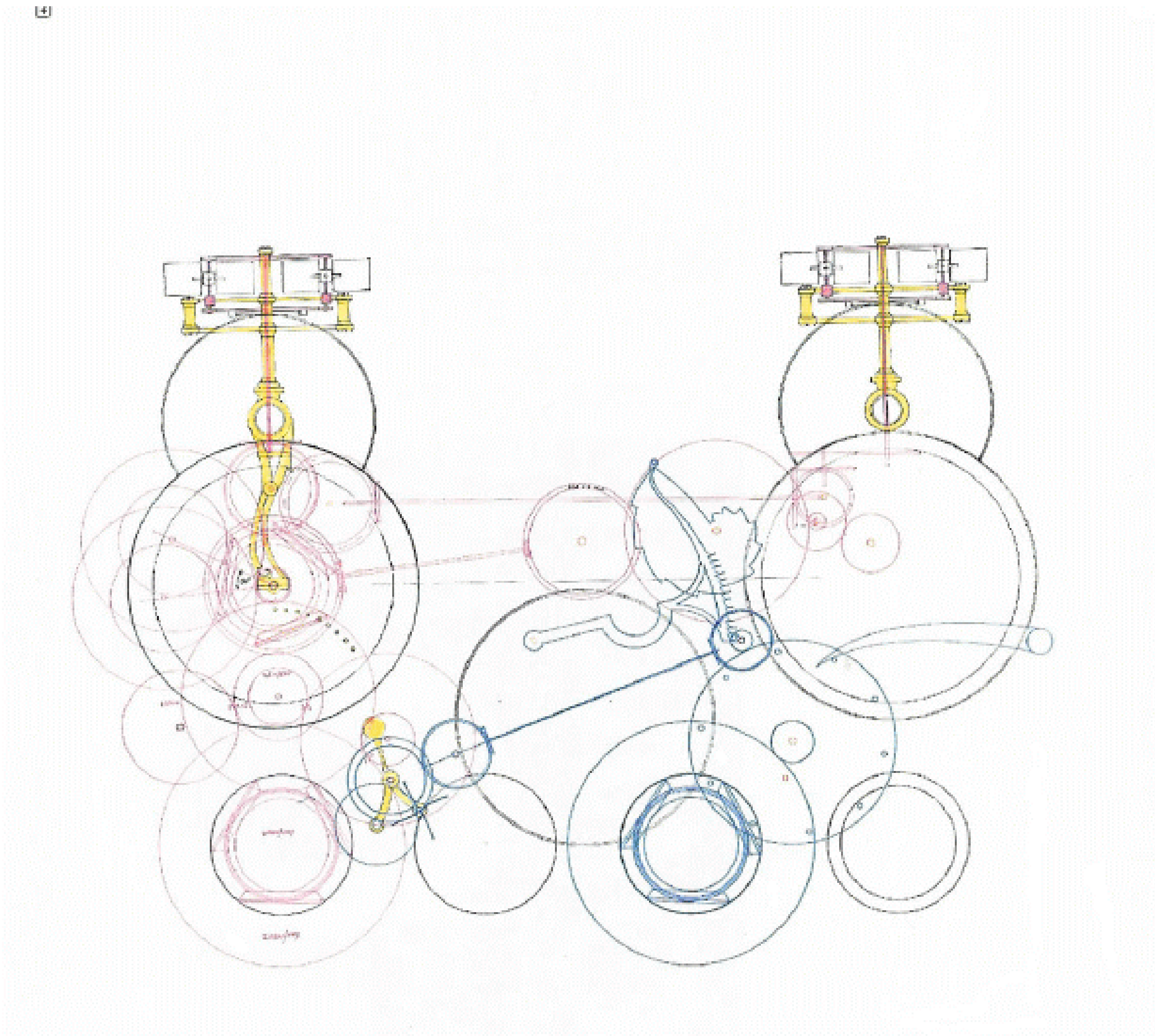
Escape wheels and planisphere



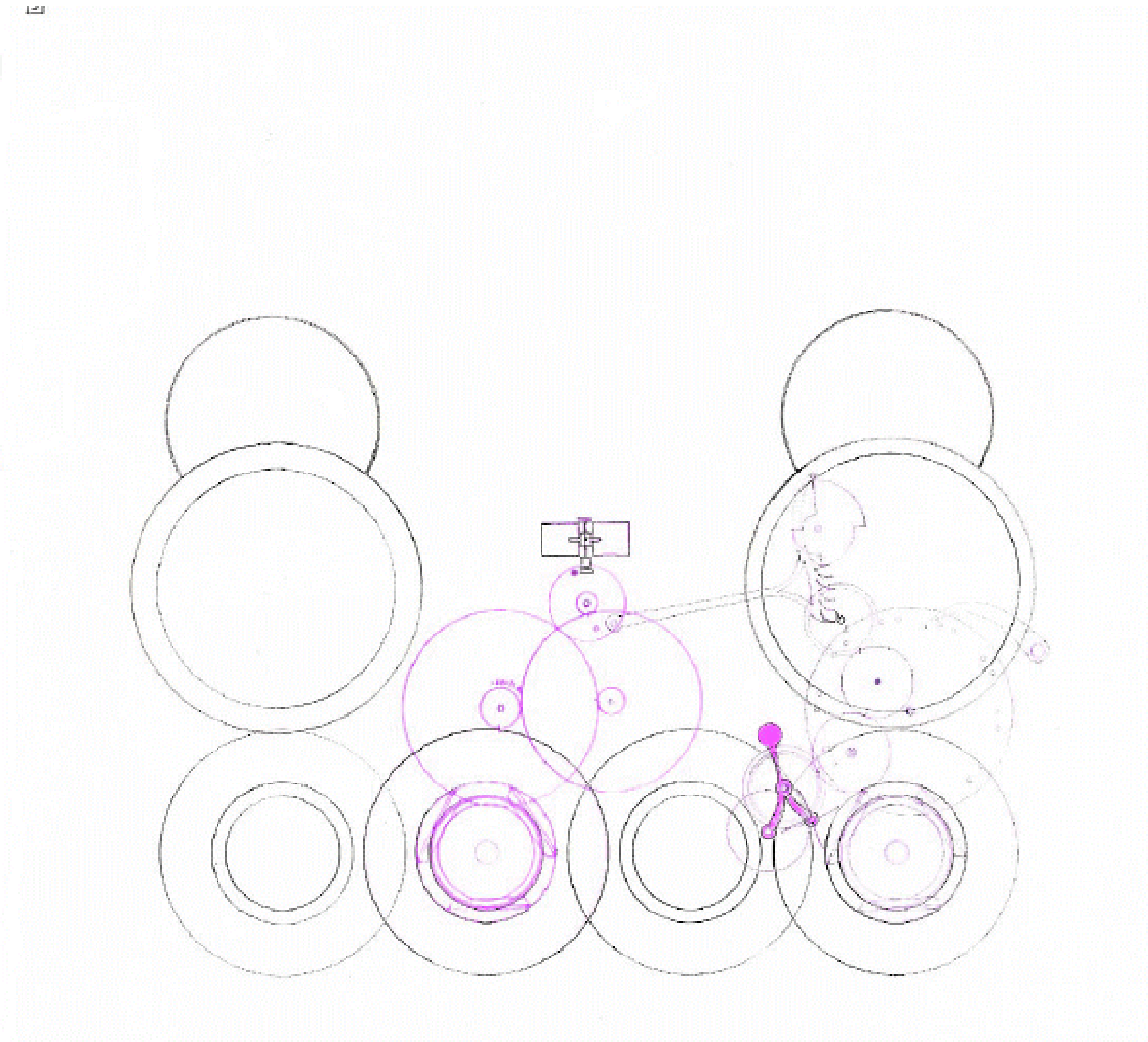
Calendar work and celestial train



Going train and hour strike train



Quarter strike train



Frame design

Balances